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Monitoring Plant Invasions in the National Forests of the United States

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MONITORING PLANT INVASIONS IN THE NATIONAL FORESTS OF THE UNITED STATES

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Abstract. We modified the United States Department of Agriculture (USDA) Forest Service, Forest Health Monitoring (FHM) program's understory plant sampling methods to better monitor native and non-native plant diversity in the Nation's forests. Single-scale, small quadrat techniques were augmented with larger-scale plots in the nationwide sampling of the nation's forests (1 plot/63,942ha). Data from 316 plots from pilot studies in eight states (Colorado, Delaware, Michigan, Oregon, Pennsylvania, Virginia, Washington, and Wyoming) showed that

52% of the forest plots had been invaded by at least one non-native species. Areas of high native diversity were most heavily invaded. Non-native species richness was significantly, positively correlated with native species richness ($r = 0.33$, $P < 0.001$), and the cover of non-native species was significantly, positively correlated to non-native species richness ($r = 0.65$, $P < 0.001$). This monitoring data combined with the USDA Forest Service's Forest Inventory and Analysis (FIA) data, will allow for detailed analysis of local, regional, and national patterns of plant diversity and invasions. For example, some vegetation types (e.g., Douglas fir, mixed northern hardwoods) are far more heavily invaded than other types (e.g., Englemann spruce, sugar maple). Rangeland plots, though only three were sampled, had significantly greater cover of non-native species compared to woodland or timber habitats. Early detection of non-native plant species was significantly enhanced with the modified multi-scale vegetation sampling design. Because areas rich in native plant diversity are being heavily invaded by non-native plant species, state, federal and private managers of forests and rangelands face a formidable challenge. When fully operational in the 50 states, this national network of plant diversity monitoring will be an essential component for assessing forest health and the invasion of non-native plant species.

Key words: exotic species invasions, forest health monitoring, multi-scale vegetation sampling, plant biodiversity.

Introduction

The Forest Health Monitoring (FHM) program is a national program that makes annual evaluations of the condition, changes, and trends in the health of forest ecosystems in the U.S. (Riitters et al. 1992). The FHM program, now administered with the U.S. Forest Service's Forest Inventory and Analysis (FIA) program consists of a nationwide, uniform distribution of sample plots providing a large, unbiased sample of the nation's forests (1 plot/63,942ha). The program is designed to provide information for the evaluation of sustainable forest management based on global standards described in the Santiago Agreement (Stolte 1997). The principle ecological criteria and generally agreed upon indicators of forest health in this agreement are productivity, diversity, vitality, conservation of soil and water, and carbon cycling.

Since its inception and design tests in the early 1990s (Riitters et al. 1992), the FHM program has focused on multiple aspects of forest ecosystems including tree growth regeneration and mortality, visual crown symptoms, soil condition, contaminants in foliage, growth efficiency, vertical vegetation structure and diversity, and air pollution. Because of the initial attention focused on sampling design efficiency, extensive training of field crews, and quality control/quality assurance (Cline et al. 1995), the program has been very successful at monitoring the timber resources in the Nation's forests. However, due to changes in interagency support and decreased funding, primary emphasis was placed on tree resources, with lesser attention to plant species diversity and other ecological indicators.

Initially, vertical vegetation structure (i.e., the amount, arrangement, and composition of forest vegetation) was seen as one of the most promising indicators of biotic integrity and biodiversity (Riitters et al. 1992). There was early recognition that vegetation structure was relevant to plant species diversity (e.g., supporting the Endangered Species Act of 1973) and

habitat diversity (e.g., supporting the Federal Policy and Management Act of 1976) as an early warning system to help identify the effects of environmental stress (Stapanian et al. 1993). As initially measured in the monitoring program, species richness and cover were recorded in 12, small (1-m^2) quadrats per fully forested plot in each of four height strata; (0 - 0.61 m, 0.61 - 1.83 m, 1.83-4.88 m, and >4.88 m). Species richness by strata, species-accumulation curves, and vegetation volume by strata could be summarized at state, regional, and national scales.

We modified the original FHM methods for evaluating understory plant diversity for two reasons: (1) the total 12-m^2 area (twelve 1-m^2 quadrats) sampled was too small; and (2) the single-scale approach was inadequate to evaluate plant diversity in patchy and heterogeneous habitats which are typical of many habitats on Earth. Small quadrats miss species, especially those with low frequency of occurrence (Stohlgren et al. 1998a). Using multi-scale vegetation plots in forests and rangelands from Colorado to Minnesota, Stohlgren et al. (1995, 1997a,b, 1998a) found that ten 1-m^2 subplots captured only 40% to 50% of the plant species in a 0.1 ha area. Typically, half the non-native species in 0.1 ha plots in rangelands were missed with a series of 1-m^2 quadrats (Stohlgren et al. 1998a). It was highly likely that the twelve 1-m^2 quadrats historically used in the monitoring program missed locally rare and non-native plant species in forested sites due to the patchy distributions of understory plants in canopy gaps or along edges. The small, 1-m^2 quadrats would gather only incomplete data on plant diversity and non-native species primarily because most plant species are locally rare (>50% of the species have <1% foliar cover) and because plants are never randomly distributed on the plot or landscape (Stohlgren et al. 1998a).

The previous monitoring methodology was modified in two ways: (1) with multi-scale techniques that increased the area surveyed in each plot (Bull et al. 1998); and (2) with the addition of qualified botanists to monitoring field teams. Highly qualified botanists were needed to field-identify most of the species at each site, including many locally rare species and invasive species from Europe, Asia, Africa, South America, and Australia. In this pilot study, a random subset of monitoring plots in various forest types in different regions added an "extended survey" of plant diversity on each of four subplots (Fig. 1). In each plot we recorded cover by species in the twelve 1-m^2 quadrats and surveyed the presence of all native and non-native plant species for each of the four 168-m^2 subplots.

The primary objectives of this pilot project were to improve and test the modified vegetation indicators (i.e., understory diversity and general vegetation structure) and provide better data on plant diversity and non-native plant invasions in the Nation's forests. We also demonstrated the potential of multi-scale plant diversity data (i.e., from quadrat to statewide scales) to evaluate hotspots of non-native plant invasions and the early detection of non-native plant species.

Study Areas

Plant structure and diversity data were collected in 316 plots across Colorado (n=33), Delaware (n=39), Michigan (n=71), Oregon (n=44), Pennsylvania (n=81), Virginia (n=15), Washington (n=12), and Wyoming (n=21) in conjunction with annually scheduled monitoring in those states (Fig. 1). Ancillary data generally included: longitude and latitude, elevation, vegetation type

(e.g., pinyon-juniper, ponderosa pine, gambel oak), and primary land use (timberland, woodland, and rangeland). All plots were located and established using standard FHM methods (Bull et al. 1998).

Methods

Plot locations were pre-determined from an unbiased systematic sampling grid, which covers the U.S. (Stolte 1997). On each of the four subplots per plot, crews established three 1-m^2 quadrats at 4.6 m on 30°, 150°, and 270° azimuths from the subplot center (Fig. 1).

Botanists on the crews used a PVC (polyvinyl chloride) frame to delineate the 1-m^2 vegetation quadrat. They then identified and estimated cover for all species in stratum 1 (0 to 0.61 m) and stratum 2 (0.61 to 1.83 m), with ground variables recorded in stratum 1. For each quadrat, crews recorded species identification, strata, and plant canopy and ground variable cover. Species codes used for analysis were the standardized USDA Natural Resource Conservation Service (NRCS) PLANTS Database codes. The height stratum of the plant was recorded with foliar cover estimated to the nearest percent. Cover was also recorded for the following ground variables: wood, water, rock, roots, duff/litter, lichen, moss, soil, trail/road, dung, and other (trash, bones, etc.; Bull et al. 1998). Data were collected between 1997 and 2001.

The 1-m^2 quadrat frame was calibrated (painted in 10 centimeter sections) to improve the accuracy and precision of cover estimates (Fig. 1). Botanists were carefully trained to estimate cover. Cover was estimated only on plants or portion of plants that were inside the quadrat frame. After completing the three quadrats on a subplot, the botanist searched the entire subplot and recorded any new species not found in the quadrats. Cover classes (5% classes) were assigned to any new species encountered and general comments about the subplot were recorded. Botanists repeated this process for all subplots. Unknown plants found on the subplots were

collected off-plot, pressed, and were later identified or mailed to the herbarium at the University of North Carolina-Chapel Hill Biota of North America Program for species identification. At a minimum, we obtained the number of unique species on each plot, even if identifications could not be made to the species level due to the stage of growth at the time of collection.

All statistical analyses were conducted with SYSTAT (SPSS, Inc. version 10.0). Due to the small sample sizes in the pilot study, the non-parametric Kruskal-Wallis tests were used to compare plant diversity characteristics among states, vegetation types, and land use classes. Simple linear regression was used to correlate native and non-native species richness and cover with $\log_{10}(X+1)$ transformed data (to improve normality). Kriging was used to map interpolations of non-native species richness in Michigan. Regression tree analysis was used to further explore the relationship between non-native species richness and cover in 1-m^2 quadrats. Regression tree analysis begins with all cases (plots) in one cluster and splits the data attribute by attribute into a hierarchical binary tree. The terminus of each branch represents a cluster whose members are more similar to each other than to members of the twin cluster (SYSTAT 2001, version 10). All default options were used to determine stopping rules and loss functions. This creates a parsimonious model with a simple branching structure in most cases. Besides non-native species richness, the other independent variables entered into the model included native species richness and cover, and live and dead basal area of the subplot. These latter variables were not significant. The variation explained by the independent variables was presented as "proportion reduced error" values, PREs, which are similar to R^2 values.

Results

There was considerable variation found in plant diversity from the eight pilot states. For example, native species richness per plot ranged from 6 species in a Colorado plot to 87 species in plots in Oregon and Virginia. Non-native species richness per plot ranged from 0 species in many plots to 21 species per plot in Oregon. The cover of non-native species ranged from 0% to 65% in the one Oregon plot that contained 21 non-native species. For the 316 plots in the eight states, the mean cover of native species was 38.9% (± 2.5%; 1 S.E.), while the mean cover of non-native species was just 1.7% (± 0.3%). These preliminary results are not intended to imply conditions throughout vegetation types, states, or the nation, and they may not be representative of various land use classes, but a wide range of habitats was tested. Given this wide range of responses from the initial data set, the following results were selected to demonstrate the potential of the combined FHM-FIA data once the program becomes fully operational throughout the nation.

Improved measurement of plant diversity and early detection of invasive non-native plants

One major feature of the revised vegetation sampling method included searching the four 168-m^2 subplots for additional plant species not previously recorded on the twelve 1-m^2 quadrats. We found that searching the larger plots aided in the early detection of non-native plant species. For all 316 plots, sampling only the twelve 1-m^2 quadrats resulted in capturing on average 33.5% (± 3.3%) fewer non-native plant species per plot. When only one non-native plant species was

found on a plot, the twelve 1-m^2 quadrats missed the species 47.5% of the time. On average, the quadrats also missed 32% (± 1.4%) of the native plant species on each plot. These were primarily locally rare, patchily distributed plant species. Thus, searching the larger subplots significantly improved measurements of native plant diversity and the early detection of non-native plant species.

Assessing patterns of plant diversity among states

Kruskal-Wallis test results identified significant differences among states in native and non-native plant species richness and cover per plot (Table 1). For example, these early results shoed that Virginia (51.9 ± 5.6 species/plot) had more than twice the native species per plot compared to Colorado (21.5 ± 1.5 species/plot) and Michigan (24.7 ± 1.2 species/plot). Washington (5.2 ± 1.4 species/plot) had four more non-native species per plot than Pennsylvania and Delaware (<1 non-native species/plot).

The states also varied in the cover of native and non-native plant species (Table 1). The initial plots in Colorado had much lower foliar cover of native species compared to the other states. Non-native species cover was highly variable locally and across states.

Preliminary comparisons among vegetation types and land use types

The data begin to provide a means to identify forest types and ecological units where non-native plant species have become well established. For example, this preliminary data showed that non-

native species cover was particularly low (<1.0%) in the Englemann spruce, red maple, and black cherry vegetation types (Table 2) compared with plots in Douglas-fir (3.0%) and mixed northern hardwoods (3.4%). Larger sample sizes are needed to confirm these patterns, particularly for rare vegetation types and habitats.

Native and non-native species cover varied significantly by primary land-use type (Table 3). The three rangeland plots had the greatest cover of non-native species. Woodland plots typically had the lowest native and non-native species richness and foliar cover compared to the other primary land-use types (Table 3). Again, additional sampling, particularly in non-forested areas, is needed to confirm these patterns (see Discussion).

Relationship of native and non-native plant species richness and cover across scales

The relationship of native to non-native species richness was greatly affected by study location (state) and the spatial scale of the data (1-m^2 versus 768-m^2 areas). The data from the eight states sampled showed weak relationships between native and non-native species richness in most states at the 1-m^2 scale. Only two states showed significant relationships, but 7 of 8 regression slopes were positive. For all states combined, areas of high native plant diversity were heavily invaded by non-native species at the 1-m^2 scale ($P < 0.003$), but < 2% of the variance was explained. At the 768-m^2 plot scale, 7 of 8 regression slopes were markedly steeper, 4 states had significantly positive relationships, and for all states combined, non-native species richness was significantly, positively correlated with native species richness ($r = 0.33$, $P < 0.001$).

There were significant positive relationships between species richness and cover. For the 316 plots in the eight states, native plant species richness was significantly correlated to native foliar cover ($r = 0.31$, $P < 0.001$). Non-native species cover was significantly positively correlated to native species richness ($r = 0.15$, $P < 0.008$). The cover of non-native species was significantly, positively correlated to non-native species richness ($r = 0.65$, $P < 0.001$).

Using the 2900 1-m^2 quadrats from all the plots, regression tree analysis showed that the first major branching in the dataset for estimating non-native species cover occurred with quadrats of < 2 or ≥ 2 non-native plant species (Fig. 2). Quadrats with 2 or more non-native species averaged 19% cover compared to <1% cover when quadrats had 1 or no non-native species. If more than five non-native species were found in a quadrat (only 5 quadrats), non-native species cover jumped to over 73%.

Discussion

Are the nation's forests being invaded by non-native plants?

The data from the eight-state pilot program showed consistent and important patterns. Non-native plant species have successfully invaded the most species-rich understory sites (Table 4), the cover of non-native plant species was significantly positively correlated with non-native species richness, and 52% of the plots contained at least one non-native plant species (Table 1). These patterns have also been observed in hundreds of 0.1-ha plots in Rocky Mountain National Park, Colorado, and the Central Grasslands (Stohlgren et al. 1999a, 2002), in riparian zones in

the Central Grasslands (Stohlgren et al. 1998a,b), in southern Utah (Stohlgren et al. 2001), and in the Pacific Northwest (DeFerrari and Naiman 1994). These findings contradict generally accepted theories (Case 1990) and small-scale experiments (Tilman 1997) that suggest that areas of low diversity and cover should be more easily invaded than species rich areas that presumably monopolize resources and inhibit invasions (Tilman 1999).

Still, on average, non-native species represent about 6% of the species, and a little over 4% of the foliar cover in the plots (Table 1). Yet, we believe there is reason for concern because of the strong positive relationship between non-native species richness and cover, particularly at the 1-m^2, plant-neighborhood, scale (Fig. 2). The data from the 2900 quadrats suggest that non-native species cover jumps dramatically on sites that contain 2 or more non-native plant species. The 19% cover of non-native species represents two-thirds or more of typical native species cover values in most states (Table 2). Very rarely are more than four non-native species were found in a 1-m^2 quadrat (only 5 times), but this gives an indication that non-native species cover can be substantial in such cases. This may occur in heavily disturbed sites, after recent fires, or along roads and riparian zones. Although the causes remain unknown, these data suggest that there may be thresholds where once a few non-native species can establish in a plant neighborhood, they may become locally dominant.

Early detection of invasive non-native plant species

Early detection may be the strongest defense against invasive species because control efforts are considerably less expensive for small populations (Westbrooks 1998). The modified multiple-

scale plot techniques aid in the early detection of invasive species. The series of twelve 1-m^2 quadrats previously used in the monitoring program missed, on average, about 33% of the native and non-native species per plot. More importantly, when there was only one non-native species on a plot, as there was on 61 plots, the series of twelve 1-m^2 quadrats missed the species in question almost half the time. Surveying the larger areas of the entire subplot is an important component of an early detection program.

The spatial patterning of plot data may aid in early detection and in planning control efforts (Fig. 3). In Michigan, for example, simple kriging diagrams show a general pattern of decreasing invasion from the southeast to northwest Michigan. This pattern might guide control efforts to the southeast part of the state, while early detection efforts might be directed to the northwest part of the state (very few non-native species) or to sites with 2 or more non-native species to prevent areas from multiple species invasions and possibly increasing non-native species cover (Fig. 3).

Land use and adaptive management

Similar to other studies (Stohlgren et al. 1997a, 1998a, 1999a, 2001, 2002), some vegetation types appear more vulnerable to invasion by non-native plant species (Table 2). Wildfires and land-use change can radically alter the richness and cover of invasive plant species. We focused here on simple measures of invasion (richness and cover) rather than economic and ecological effects of individual and groups of non-native species. Many non-native plant species invading hotspots of native species richness can be noxious (poisonous) and may affect species

assemblages of native plants, birds, and butterflies (Simonson 1998). Additional ecological and economic analyses are needed to more fully develop strategic control programs.

Other factors such as ground disturbance by small mammals, proximity to disturbed roadsides and riparian zones, and proximity to infested urban sites, etc., may be major contributors to these trends (Stohlgren et al. 2002). The real power in regional-scale analyses will come after several years of data collection, and after some plots are re-sampled for a second and third time to better evaluate spatial and temporal variation with larger sample sizes in multiple regions. The FHM-FIA monitoring program will continue to provide much needed data on the effects of various land-use practices on the nation's forests. More importantly, the spatial attributes of the data allow for immediate use in controlling invasive plant species (Fig. 3). The data are designed to be immediately accessible to land managers for early detection of noxious weeds, protection of rare/unique plant species and habitats, and to identify those forests needing immediate management attention.

Many of these plots may have had non-native species nearby in forest clearings and riparian zones, along roadways, and on rangelands. Finding that species-rich areas are being more heavily invaded than species-poor areas (Table 4) complicates non-native species control efforts in the nation's forests. With mandates and policies to protect native species diversity, it may be more difficult to broadcast herbicides on hotspots of native and non-native species richness. More targeted chemical and biological control may be needed to battle non-native plant invasions.

Conclusion

The FHM-FIA Program is the first, statistically sound, quality assured, multi-scale assessment of native and non-native plant diversity in the Nation's forests. A greatly expanded data set will document hotspots of native plant diversity and primary areas of invasion by non-native plant species, determine the effects of land use practices on plant diversity, and aid in evaluating the condition of the Nation's forests. Such information is vital to adaptive management, prescribing control efforts for invasive species, and aiding in the preservation of native biodiversity. The multi-scale vegetation sampling methods are directly comparable to multi-scale vegetation sampling techniques used by the U.S. Geological Survey, National Park Service, Bureau of Land Management, Smithsonian Institution, and others (Stohlgren et al. 1999a, Stohlgren et al. 2002). This greatly expands the potential for multi-agency collaboration for local, regional, and national evaluations of plant diversity and plant invasions. The current monitoring strategy could be augmented by stratified random sampling in rare and important habitats and in areas of high risk of invasion by non-native species (frequently missed by any systematic sampling grid), and by developing comparable data sets in non-forested areas. At present, the number and cover of non-native species is just 6% to 4% of total species richness and cover respectively, but some quadrats had over 100% cover of non-native species. Mapped displays of the data (Fig. 3) will become increasingly important in identifying and protecting areas of high native plant diversity, controlling invasive and noxious plant species, and synthesizing species-environment data for predictive modeling.

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References

Bull, K.A., Stolte, K.W., and T.J. Stohlgren. 1998. Forest Health Monitoring: Vegetation Pilot Field Method Guide. USDA Forest Service, Washington, DC.

Case, T.J. 1990. Invasion resistance arises in strongly interacting species-rich model competition communities. In: Proceedings of the National Academy of Science **87:** 9610-9614.

Cline, S.P., Alexander, S.A., and J.E. Barnard. (eds) 1995. Environmental Monitoring and Assessment Program Forest Health Monitoring Program Quality Assurance Project Plan for Detection Monitoring Project. In: Environmental Monitoring Systems Laboratory Report. EPA/620/R-95/002, United States Environmental Protection Agency, Las Vegas, NV 89119.

DeFerrari, C.M., and R.J. Naiman. 1994. A multi-scale assessment of the occurrence of exotic plants on the Olympic Peninsula, Washington. Journal of Vegetation Science 5: 247-258.

Riitters, K.H., Law, B.E., Kucera, R.C., Gallant, A.L., DeVelice, R.L., and, C.J. Palmer. 1992. A selection of forest condition indicators for monitoring. Environmental Monitoring and Assessment **20(1):**21-3.

Simonson, S. 1998. Rapid Assessment of butterfly diversity: a method for landscape assessment. Masters Thesis, Department of Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins, CO. 50 pages.

Stapanian, M.A., Cline, S.P. and, D.L. Cassell. 1993. Vegetation structure. In: Conkling BL and Byers GE (eds) Forest Health Monitoring Field Methods Guide, Internal Report, U.S. Environmental Protection Agency, Las Vegas, NV.

Stohlgren, T.J., Falkner, M.B., and L.D. Schell. 1995. A modified-Whittaker nested vegetation sampling method. Vegetatio **117:**113-121.

Stohlgren, T.J., Chong, G.W., Kalkhan, M.A., and L.D. Schell. 1997a. Rapid assessment of plant diversity patterns: a methodology for landscapes. Ennv. Monit. Assessment **48:**25-43.

Stohlgren, T.J., Chong, G.W., Kalkhan, M.A., and L.D. Schell. 1997b. Multiscale sampling of plant diversity: effects of minimum mapping unit size. Ecological Applications **7:**1064-1074.

Stohlgren, T.J., Coughenour, M.B., Chong, G.W., Binkley, D., Kalkhan, M.A., Schell, L.D., Buckley, D., and J. Berry. 1997c. Landscape analysis of plant diversity. Landscape Ecology **12:**155-170.

Stohlgren, T.J., Bull, K.A. and Otsuki, Y. 1998a. Comparison of rangeland sampling techniques in the central grasslands. Journal of Range Management **51:**164-172.

Stohlgren, T.J., Bull, K.A., Otsuki, Y., Villa, C., and M. Lee. 1998b. Riparian zones as havens for exotic plant species. Plant Ecology **138:**113-125.

Stohlgren, T.J., Binkley, D., Chong, G.W., Kalkhan, M.A., Schell, L.D., Bull, K.A., Otsuki, Y., Newman, G., Bashkin, M., and Y. Son. 1999a. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs **69:** 25-46.

Stohlgren, T.J., Schell, L.D., and B. Vanden Heuvel. 1999b. Effects of grazing and soil quality on native and exotic plant diversity in Rocky Mountain grasslands. Ecological Applications **9:** 45-64.

Stohlgren, T.J., G.W. Chong, L.D. Schell, K.A. Rimar, Y. Otsuki, M. Lee, M.A. Kalkhan, and C.A. Villa. 2002. Assessing vulnerability to invasion by nonnative plant species at multiple spatial scales. Environmental Management 29: 566-577.

K. W. Stolte. 1997. 1996 National Technical Report on Forest Health. Admin. Report FS-605, Asheville, NC. U.S. Department of Agriculture, Forest Service, Southern Research Station. 47pp.

D. Tilman. 1997. Community invisibility, recruitment limitation, and grassland biodiversity. Ecology **78:**81-92.

D. Tilman.1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecology **80:**1455-1475.

R. Westbrooks. 1998. Invasive plants, changing the landscape of America: Fact book. Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICNMEW), Washington, D.C. 109 pp.

Table 1. Mean native and non-native plant species and foliar cover in the initial 316 plots in eight pilot states with Kruskal-Wallis (K-W) tests among states. Standard errors are in parentheses.

States	Native Species	Non-native Species	Native Cover (%)	Non-native Cover (%)	% Invaded Plots	No. Plots
Colorado	21.5 (1.5)	1.4 (0.3)	35.0 (3.0)	1.4 (0.4)	64%	33
Delaware	25.0 (1.7)	0.9 (0.2)	15.7 (2.3)	2.2 (1.2)	46%	39
Michigan	24.7 (1.2)	1.5 (0.2)	76.5 (8.6)	2.5 (0.8)	55%	71
Oregon	26.8 (2.3)	3.1 (0.7)	21.0 (2.9)	2.1 (1.4)	64%	44
Pennsylvania	25.6 (1.1)	0.9 (0.2)	32.4 (2.3)	0.6 (0.3)	31%	81
Virginia	51.9 (5.6)	2.2 (0.6)	18.9 (3.7)	2.6 (1.1)	73%	15
Washington	36.8 (4.2)	5.4 (1.4)	45.2 (9.2)	2.5 (1.0)	92%	12
Wyoming	39.8 (2.7)	1.5 (0.5)	34.6 (2.7)	1.0 (0.6)	57%	21
Combined	27.7 (0.8)	1.7 (0.2)	38.9 (2.5)	1.7 (0.3)	52%	316
K-W =	54.8	37.8	86.5	18.6		
P<	0.001	0.001	0.001	0.009		

Table 2. Mean species richness and foliar cover in 768-m^2 plots for vegetation types with 10 or more plots and all states combined, with Kruskal-Wallis (K-W) test. Standard errors are in parentheses.

Vegetation Type	Native Species	Non-native Species	Native Cover (%)	Non-native Cover (%)	No. of Plots
Ponderosa Pine	21.8 (2.8)	2.7 (0.7)	21.7 (3.6)	1.2 (0.6)	19
Douglas Fir	35.2 (2.8)	4.2 (0.9)	37.3 (4.7)	3.0 (2.0)	33
Loblolly Pine	35.6 (5.6)	1.2 (0.4)	16.0 (4.1)	1.1 (0.5)	13
Mixed Northern Hardwood	28.0 (2.6)	1.3 (0.5)	30.9 (2.9)	3.4 (1.9)	21
White Oak	26.4 (2.7)	1.1 (0.3)	18.7 (4.8)	1.9 (1.2)	16
Red Maple	24.0 (0.3)	0.7 (0.3)	27.4 (3.4)	0.6 (0.3)	34
Black Cherry	24.1 (1.7)	0.9 (0.4)	41.1 (4.4)	0.6(0.4)	27
K-W	18.6	31.9	28.4	9.0	
P<	0.006	0.001	0.001	0.174	

Table 3. Example Kruskal-Wallis (K-W) test results of mean species richness and foliar cover in 152 plots (768-m^2) for three land-use types in Colorado, Michigan, Oregon, Pennsylvania, and Virginia. Missing data for 164 plots. Standard errors in parentheses.

Primary Land Use	Native Species	Non-native Species	Native Cover (%)	Non-native Cover (%)	No. of Plots
Timberland	31.8 (1.3)	2.1 (0.3)	32.8 (1.8)	2.2 (0.6)	135
Woodland	20.4 (1.4)	1.8 (0.6)	28.8 (4.9)	1.2 (0.6)	14
Rangeland	21.3 (3.9)	4.7 (1.8)	27.8 (7.8)	10.0 (3.4)	3
K-W	71.9	4.0	0.5	7.6	
P<	0.003	0.130	0.770	0.020	

Table 4. Correlations of native to non-native plant species richness at 1-m^2 (quadrat) scales and 768-m^2 (plot) scales for Forest Health Monitoring plots in eight states. All data were log-transformed ($log_{10}X+1$) prior to analyses.

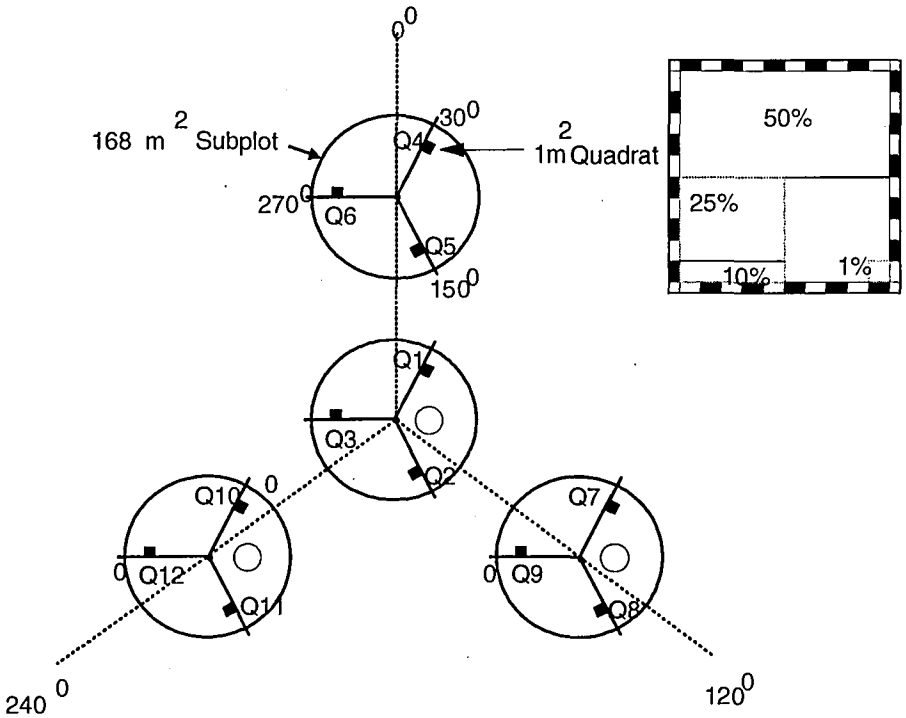
	1-m^2 Scale				768-m^2 Scale			
State	Slope	R	P	n	Slope	r	P	n
Colorado	0.002	0.005	0.932	340	0.510	0.360	0.040	33
Delaware	-0.003	0.005	0.918	398	0.270	0.190	0.248	39
Michigan	0.017	0.038	0.426	448	0.033	0.018	0.883	71
Oregon	0.009	0.013	0.810	348	0.763	0.443	0.003	44
Pennsylvania	0.013	0.036	0.269	930	0.964	0.552	0.001	81
Virginia	0.177	0.212	0.009	151	0.829	0.530	0.042	15
Washington	0.016	0.020	0.830	124	0.068	0.032	0.922	12
Wyoming	0.075	0.160	0.019	219	0.642	0.310	0.173	21
Combined	0.028	0.050	0.003	2958	0.543	0.330	0.001	316

List of Figures

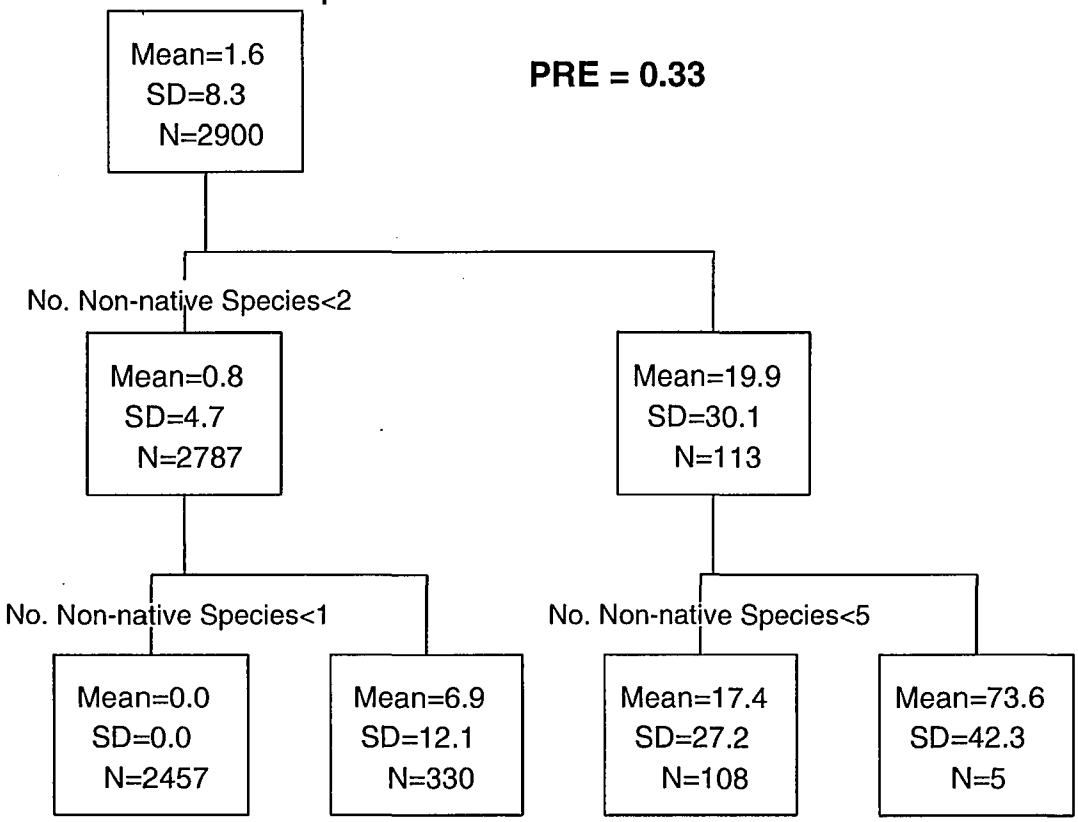
Figure 1. Multi-scale Forest Health Monitoring Program plot design. Foliar cover by species in two height strata was recorded by species in the three 1-m^2 quadrats in each 168-m^2 subplot, and the remaining area in each subplot was then surveyed for plant species not recorded in the quadrats. Four subplots comprise one plot.

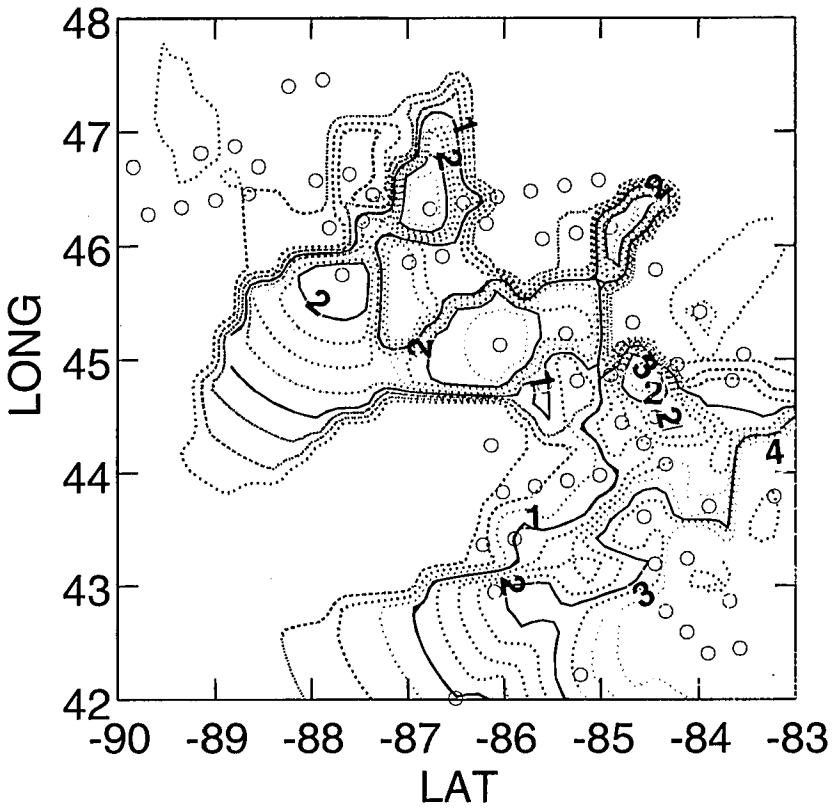
Figure 2. Regression tree analysis estimating mean non-native species richness in relation to non-native species richness in 2900 1-m^2 quadrats in eight pilot states (combined data).

Figure 3. Example contour map of non-native plant species richness for plots in Michigan. Kriging (SYSTAT 10.0) was used to interpolate between plots. Subplot locations are shown as circles except for subplots with only one non-native species, which are shown as a circle.


0 0
168 m 2 Subplot
30 0
Q4
1m 2 Quadrat
270 0
Q6
Q5
150 0
50%
25%
10%
1%
Q1
Q3
Q2
Q10
0
Q7
0
Q12
0
Q9
Q11
Q8
240 0
120 0

Cover Non-native Species

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LAT

Final Report

RMRS Copy for Library

Merrill R Kaufmann
07/08/02 11:22 AM

To: Susan Major/RMRS/USDAFS@FSNOTES
cc:
Subject: Re: Report Due on 00-JV-11221610-130

Here's the file!

[redacted]

Final report document 07022002 fhmpaper9.

<> Merrill R. Kaufmann
<> USDA Forest Service, Rocky Mountain Research Station
<> 240 West Prospect Road, Fort Collins, CO 80526
<> mkaufmann@fs.fed.us 970-498-1256

"Only the mediocre are always at their best." (Jonathan Winters)

Susan Major

Susan Major
07/08/2002 07:29 AM

To: Merrill R Kaufmann/RMRS/USDAFS
cc: Susan Major/RMRS/USDAFS
Subject: Re: Report Due on 00-JV-11221610-130

Merrill,

Electronic is fine, and then I will print two copies. One for our files and one for the RMRS Library.

Thanks for your help.

Sue

Sue Major
Clerk, Grants & Agreements
970-498-1395
smajor/rmrs
smajor@fs.fed.us
Merrill R Kaufmann

Merrill R Kaufmann
07/05/02 08:48 AM

To: Susan Major/RMRS/USDAFS@FSNOTES
cc: Cheryl Galida/RMRS/USDAFS@FSNOTES, Susan Major/RMRS/USDAFS@FSNOTES
Subject: Re: Report Due on 00-JV-11221610-130

Susan, I just received a draft manuscript which is acceptable as the final report for this JV. Would you like a hard or electronic copy? Merrill
Susan Major

Susan Major
06/22/2002 08:26 AM

To: Merrill R Kaufmann/RMRS/USDAFS, Cheryl Galida/RMRS/USDAFS
cc: Susan Major/RMRS/USDAFS
Subject: Report Due on 00-JV-11221610-130

Report Due

Agreement Number: 00-JV-11221610-130
Cooperator: Colorado State University
Principal Investigator: Dr. Dan E. Binkley/Dr. Thomas Stohlgren
Title: "Implementation of National Forest Health Monitoring Protocol for Understanding Vegetation Sampling"

Have you received and accepted the following checked item(s):

	Study plan due:	
	Work Plan due:	
	Phase I Final Report:	
X	**Final Report due:**	3/31/02
	Other:	

Based upon your response, we will either approve the cooperator's invoice for payment or return the invoice to the cooperator along with an explanation of why they cannot be paid.

Please reply by July 8, 2002.

Thank you.

Sue

Sue Major
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